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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An implementation scheme is described for a single connection, user internetwork Transmission Control Program using the Cerf-Kahn protocol. It is designed for a dedicated micro-processor and supports low delay, low through-put interactive traffic. In this preliminary documentation a detailed implementation specification is presented in an ALGOL-like notation, along with a brief discussion of its functions, user interface, control variables and data structures. A		

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Single-Connection TCP Specification  
 (Preliminary Documentation)

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## 1 INTRODUCTION

This document describes a preliminary implementation scheme for a single-connection internetwork Transmission Control Program [TCP]. It is designed to operate on a dedicated small computer with minimal operating system assistance and to support low delay, low through-put interactive traffic. Although assumed to be attached to the ARPANET via a local or remote host interface [1], only minimal changes are necessary for connection to the Packet Radio Network using the Channel Access Protocol [2].

Detailed knowledge is assumed of the internetwork TCP protocol and the reader is referred to the official specification [3] [4] for justification and further discussion of the details of the protocol.

NOTE: There have been several changes to the protocol that are not listed in the December 1974 revision [3]. Among these, addition of the Beginning Of Segment [BOS] bit and Timestamping in effect [T] bit in the control information word; addition of a 32 bit field for timestamping information and sending an ACKnowledgement for FIN requests. The final specification will be available by February, 1976.

## 2 DESCRIPTION of TCP FUNCTIONS

For maximum size reduction, only the single-connection user subset of functions are implemented. Unsupported functions are:

1) Unspecified sockets - On doing an OPEN, the user must fully specify the destination NET, TCP and PORT socket addresses, eliminating connections analogous to the NCP "listening" connection needed only by server and logger processes. (To permit a host to provide service serially through a single channel TCP, this function may be implemented later.)

2) Re-assembly of fragmented segments - Packets must have both the Beginning Of Segment [BOS] and End Of Segment [EOS] control bits asserted. If not, on passing through a gateway, the segment was broken into fragments; it should be discarded without processing. The re-construction of segments has yet to be resolved; but it can be avoided by limiting segment length (by receive window size control) to less than the gateway fragmentation threshold. Though in the future, it may become necessary to implement it.

3) ECHO and TRASH special functions - Being solely for experimentation purposes, ECHO and TRASH special

functions are not implemented. Messages containing these special functions are ignored. (If the cost penalty, mainly storage capacity, is not too high, these functions will be implemented later.)

4) Timestamping - The timestamping control bit is ignored and the contents of the returning packet's timestamp field will be undefined.

5) Parameter change/Status socket - Being strictly single-connection, there is no Parameter change/Status socket. (Note - this socket is distinct from the Well Known Socket 0.)

Except for these restrictions, the TCP insures end-to-end acknowledgement, error correction, duplicate detection, sequencing and flow control; providing the user process a reliable, error-free logical communications channel.

### 3 USER-TCP INTERFACE

Five primitives comprise the USER/TCP interface. It is intended that these routines be called via a subroutine jump or supervisor call and indicate command acceptance or rejection on exit. When complete, the user will be notified of the final disposition of OPEN, SEND and CLOSE requests. This allows user processing to proceed asynchronously and in parallel with TCP processing.

1) OPEN CONNECTION - Used to establish a connection, the OPEN primitive is passed the address of the foreign and local socket ids. If a connection already exists, the OPEN is rejected and an error returned to the caller. After checking the request and socket ids, the control variables are initialized and an Initial Sequence Number (ISN) is chosen. Since we can remember the last sequence number used on the previous connection, it is not necessary to choose a clock-based ISN, but rather just continue. (Cf. [3] section 4.3.1 for more on ISN selection.) After notifying the Net Output Process to send a SYN, control is returned to the caller. When the connection is ready for use, the user process is notified.

2) SEND LETTER - This call causes the data contained in the user buffer to be sent on the connection. The buffer address and length are stored in a common data area, the output process notified of work pending and control returned to the caller. After the

data has been packetized and sent (but not ACKnowledged), the user process is notified. Letter boundaries are ignored, every data packet has the End Of Letter (EOL) bit set. If the connection is not established, the data is queued for sending later. There can be at most one outstanding send. The mechanics of sending data is covered in section xxx.

3) RECEIVE LETTER - The user process is notified when data arrives on the connection and it is moved into user buffers by a RECEIVE. RECEIVE is called with a buffer pointer and maximum byte count and returns the actual byte count. Again, letter boundaries are ignored. After delivery to the user, an ACKnowledgement is sent to the sender. The exact details of moving data into the user buffer is covered later in section xxx.

4) INTERRUPT - A special control signal is sent to the destination indicating an interrupt condition. All unsent or unacknowledged data will be flushed. If the connection is not established, an error is returned.

5) CLOSE CONNECTION - This command causes the connection to be closed. If it is not open, an error is returned. Pending unsent or received data is flushed, no more accepted and a FIN sent to the remote TCP. Control is returned to the caller and the user is notified when the close is finalized. The exact process of closing a connection is covered later in section xxx.

#### 4 TCP STRUCTURE

##### 4.1 OPERATING ENVIRONMENT

The TCP is designed to operate under a very simple operating system structure. Each process has a process control table containing space for its run-time stack, status save area and an external event scoreboard. To signal a process of some event, the signalling process sets a bit in the called process' scoreboard. Each process is responsible for periodically polling its scoreboard and acting appropriately. After processing the signal, the process then clears the flag bit. Each process runs to completion and context switching happens only when a process explicitly releases control. The only operating system primitive is one that causes the context to switch to the next active process. All processes run at the same priority level.

Using a scoreboard has three important restrictions. It is not possible to maintain temporal ordering of signals, multiple signals of the same type are condensed into one, and it is not possible to transfer any data along with the signal. The first two restrictions are not critical to the TCP implementation; indeed, a TCP implementation running under a normal message queueing operating system must go to some effort to remove extraneous signals resulting from process asynchrony. The third restriction requires putting data associated with an event in a "global" location known to both processes.

There must also be I/O devices and their associated device driver routines. It is assumed that the devices are interrupt driven, though programmed device polling is possible at reduced data rates. The following devices are needed:

- 1) Net input device -
- 2) Net output device -
- 3) Hardware timer -

#### 4.2 NETWORK INTERFACE

To allow the TCP to be used with computer networks of different structure and interfacing requirements, all network dependent code is concentrated in three routines. While designed for the ARPANET and Packet Radio Network this partitioning should be adequate for most other network configurations. (The most obvious exception is the Very Distant Hosts in the ARPANET; which require an additional watchdog process to provide control functions for the IMP-HOST line protocol used (Cf. [1] appendix F).) The routines and their functions are:

**INITIALIZENETWORK** - Called on system initialization, this routine initializes the device driver routines and performs the HOST-NETWORK start-up sequence. It returns when the network is ready to deliver/accept messages to/from the host computer.

**NETINPUT** - Passed the address of a packet buffer, this routine initiates action to accept a message from the network. It performs the network-dependent processing of the NETWORK-HOST message header, e.g. in the ARPANET, it would verify that the message is of type 0 (regular packet) and not a special IMP-HOST message. Control returns to the caller when a valid message is received.

**NETOUTPUT** - Called with the address of a message to send, this routine performs the network-dependent formatting of the HOST-NETWORK message header. Transmission of the message

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into the network is started and control returned to the caller when the output is completed.

#### 4.3 PROCESS INTERACTION

The TCP is composed of two processes, appropriate device drivers and a set of user-callable routines sharing a common data base, the Transmission Control Block. Each process is non-interruptable, running to completion, and communicates via signal flags. The TCP INPUT process handles incoming messages and either notifies the user process of new data received or signals the TCP OUTPUT process to send error packet or various control packets. The input process is the only process that receives data from the net and likewise, the output process is the only sender of data to the network. The TCP OUTPUT process, on command, sends error packets or control packet on request of the input process or data on request of the user process. It also is responsible for retransmitting unACKnowledged data periodically. The Network device driver also communicates via signals, notifying the caller of "done." The hardware timer interrupts the computer periodically and its device driver signals the output process for packet retransmission.

#### 4.4 CONNECTION CONTROL VARIABLES

All of the information local to a specific connection is kept in a Transmission Control Block [TCB]. The following are the fields of the TCB and their length.

DHOST - (16 bits) The local PSN address of the destination host or gateway. For simplicity, it is assumed that the local host address is the same as the TCP address if in the local network. Otherwise, the destination NET id is used to determine the local gateway address.

DNET - (8 bits) The destination network id. (Cf. [3] section 4.2.1 for list of assigned network ids.)

DTCP - (16 bits) The destination TCP id.

DPORT - (24 bits) The destination PORT id. Along with DNET and DTCP, they form the destination socket.

SNET - (8 bits) The network id of the local network.

STCP - (16 bits) The TCP id of the local TCP.

SPORT - (24 bits) The local PORT id. Along with SNET and STCP, they form the local socket number.

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CONNECTIONSTATE - (8 bits) The actions performed by the TCP depend upon what has happened previously. There are six "connection states" in a user TCP. They are:

- 1) CLOSED - The connection, as such, does not exist.
- 2) SYNSENT - The user process has done an OPEN and a SYN has been sent to the foreign TCP in an attempt to establish a connection. We wait for the ACKnowledgement of our SYN before going to the ESTABLISHED state and notifying the user process that the connection is usable.
- 3) SIMULINIT - After sending a SYN to establish a connection, we received a SYN without an ACKnowledgement of our SYN from the foreign TCP. This represents an attempt by both ends to open the connection simultaneously. We send an ACKnowledgement of the SYN we received and initialize the connection dependent variables. We wait for the ACKnowledgement of our SYN before going to the ESTABLISHED state and notifying the user process that the connection is usable.
- 4) ESTABLISHED - The three-way handshake to synchronize the connection was successful and the connection is usable for data transfers.
- 5) FINWAIT - The user process has done a CLOSE and we have sent out the FIN. We wait for the FIN to timeout or to receive a FIN and ACKnowledgement of our FIN before going to the CLOSED state.
- 6) FINRECEIVED - We have received a FIN from the foreign TCP. The user is notified of the remote close and we send a FIN and ACKnowledge the receive FIN. We now wait for an ACKnowledgement of our FIN or its timeout before going to the CLOSED state.

RCVSEQ - (32 bits) The next sequence number expected

RCVWS - (16 bits) The receive window size.

INITSEQ - (32 bits) The initial receive sequence number used by the foreign TCP. This is used to detect old duplicates of the SYN that established the connection.

SNDSEQ - (32 bits) The next sequence number to send.

SNDWS - (16 bits) The send window size.

LASTWSEQ - (32 bits) The last sequence number used to update send window.

LSWEDGE - (32 bits) The left send window edge sequence number.

INPUTHEAD - (16 bits) The pointer to the head of the receive data reassembly ring buffer.

BUFFERPOINTER - (16 bits) The address of the start of the user's send buffer.

BUFBYTECOUNT - (16 bits) The number of bytes in the user's send buffer. The byte count and buffer pointer are set when the user does a send and are updated as the output process removes and sends data.

RTXWAKEUP - (16 bits) Count of the number of retransmissions sent without receiving any new ACKs. It is cleared when a valid ACK comes in. When the number of retransmissions exceeds a preset value, the user is notified of "TCP not responding."

RTXPOINTER - (16 bits) The pointer to the head of the retransmission ring buffer.

RTXCOUNT - (16 bits) The number of bytes of data in the retransmission buffer.

RTXCONTROL - (16 bits) It contains the control field of the control packet queued up to be retransmitted. If zero, then no control packet queued up. Only one control packet can be queued for retransmission.

RTXCNTRLSEQ - (32 bits) The send sequence number of the control packet queued up to be retransmitted.

RTXDATASEQ - (32 bits) The send sequence number of the data byte at the head of the retransmission ring buffer.

In addition, there are several assembly-time constants that set the size of various buffers.

MAXPACKETSIZE - The maximum number of data bytes that can be put in the text field of a internet packet. MAXPACKETSIZE, internetwork header length and length of local PSN control fields determine the size of the send packet buffer.

MAXRCVWS - The maximum receive window size is set by the size of the reassembly ring buffer.

MAXRTXCOUNT - The maximum amount of data queued up to be retransmitted. This determines the size of the retransmission ring buffer.

There are also several buffers associated with the connection. They are:

RCVPKTBUFFER - The buffer that incoming packets are written into by the network device driver.

REASSMBUFFER - The ring buffer where input data is reassembled and stored pending deliver to the user process.

REASSMFLAGS - A boolean vector that indicates which elements of the reassembly buffer contain a data octet.

SENDPKTBUFFER - The buffer that outgoing packets are constructed in and sent out by the network device driver.

RTXBUFFER - The buffer where data waiting to be ACKnowledged is enqueued.

#### 4.5 INPUT PACKET HANDLER

After initializing the local network interface, the TCP INPUT process is awakened when a packet arrives from the network. The packet is checked for an internetwork message; malformed packets are simply discarded. The validity check involves verifying that the message is long enough to contain the TCP packet header and the packet header version number is correct. The BOS and EOS control bits must both be asserted; the current implementation can not handle fragmented segments. The checksum is finally calculated and detectably damaged packets are discarded; they will be re-transmitted by the sender.

After validation, the message is checked for special function or error information and processed appropriately. In this preliminary specification, their handling is not detailed; but the TCP must be sensitive to RESET ALL, RESET and QUERY special functions and all error conditions.

Packets without control dispatch refer to specific connections; the foreign and local sockets are checked against those of the single connection we service. If different, an error message (connection non-existent) is constructed and queued to be sent by the Net Output Process.

If in the SYNSENT state and we receive a SYN with INT, DSN or FIN then the SYN is malformed and an error is returned. If the packet acknowledges the SYN we sent, the connection is synchronized. We ACKnowledge the received SYN, initialize the Transmission Control Block and notify the user of connection establishment. If instead of an ACK, the packet contains only a SYN, then we have a simultaneous attempt by both sides to open the connection. (Cf. [3] section 4.3.2 for details of SYN collision.) The new connection state is SIMULINIT.

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In the SIMULINIT state, if we receive a SYN it is first checked to see if it is a duplicate of the SYN that caused the state change to SIMULINIT. If so, then just ACKnowledge receipt. Otherwise we have two different SYNs and can not tell which is valid, so we send back an errcr and reinitialize. If instead of a SYN, we get an ACKnowledge of our SYN, the connection has been established by a four-way handshake. Notify the user and process any data that may accompany the ACK.

Once the connection is established, errors are sent for all SYNs received, except for duplicates of the original.

## 5 USER INTERFACE LOGIC DOCUMENTATION

```

OPEN (OPENBLOCKPOINTER):
  if CONNECTIONSTATE notequal CLOSED then
    return (connection already open error)

  (move socket addresses into control block)
  (convert DNET,DTCP address into local PSN host/gateway address)
  RCVWS: =MAXRCVWS
  INITCONNECTION
  comment- return to caller. notify user process when connection
  becomes established or on error condition.
  return (ok)

SEND (BUFFERADDRESS, BUFFERLENGTH):
  comment- put buffer pointer and length into TCB for send process
  if BUFBYTECOUNT notequal 0 then
    return (too many SENDs error)
  else
    begin
      BUFFERPOINTER: =BUFFERADDRESS
      BUFBYTECOUNT: =BUFFERLENGTH
      (notify TCP OUTPUT PROCESS to send data)
    end
  return (ok)

INTERRUPT
  if CONNECTIONSTATE notequal ESTABLISHED then
    return (connection not open error)

  (notify TCP OUTPUT PROCESS to flush send data)
  (notify TCP OUTPUT PROCESS to send INT)
  return (ok)

RECEIVE (BUFFERADDRESS, BUFFERLENGTH, result BYTECOUNT):
  if CONNECTIONSTATE notequal ESTABLISHED then
    return (connection not opened error)

  PTR: =BUFFERADDRESS
  BYTECOUNT: =0

  while (BYTECOUNT < BUFFERLENGTH) and REASSMFLAGS(INPUTHEAD) do
    begin
      user buffer (PTR) := REASSMBUFFER (INPUTHEAD)

```

```
REASSMFLAGS (INPUTHEAD) := FALSE
PTR:=PTR+1
INPUTHEAD := (INPUTHEAD+1) MOD MAXRCVWS
BYTECOUNT:=BYTECOUNT+1
end

RCVSEQ := RCVSEQ + BYTECOUNT
(notify TCP OUTPUT PROCESS to send ACK)

if REASSMFLAGS (INPUTHEAD) then
  (notify user process of data remaining to be received)
return (ok)

CLOSE:
case CONNECTIONSTATE of
  -SYNSENT:
  DELETECONNECTION

  -SIMULINIT:
  -ESTABLISHED:
  begin
    CONNECTIONSTATE:=FINWAIT
    (notify TCP OUTPUT PROCESS to flush send data)
    (notify TCP OUTPUT PROCESS to send FIN)
  end

  -CLOSED:
  -FINWAIT:
  -FINRECEIVED:

return (ok)
```

## 6 TCP INPUT PROCESS LOGIC DOCUMENTATION

## TCP INPUT PROCESS:

(wait for network interface initialization)

## LOOP: NETINPUT (RCVPKTBUFFER)

```
if (packet length greaterthan or equal minimum permitted) and
  (packet header version number equal 0) then
  begin
    comment- packet verified as a TCP message.
    if (packet BOS bit =1 and packet EOS bit =1) then
      begin
        comment- unfragmented message, process.
        if CHECKSUM (RCVPKTBUFFER) = 0 then
          comment- checksum ok, packet not damaged.
          if (packet Control Dispatch bits equal 0) then
            HANDLEREGULARPACKET
          else
            HANDLESPECIALPACKET
        end
      else
        comment- fragmented message. code to do fragment
        reassembly goes in here, but for now just...
        (log error)
    end
  else
    comment- garbage packet
    (log error)
  goto LOOP
```

## CHECKSUM (PACKETPOINTER):

```
comment- computes the 16 bit 1's complement sum of the header
  and text fields of the packet. if the sum is 0, then the
  packet is not (hopefully!) damaged.
```

## HANDLEREGULARPACKET:

```
if ADDRESSCHECK then
  begin
    comment- packet is for this connection, process according to
    connection state.

  case CONNECTIONSTATE of
    -SYNSENT:
      if (packet SYN bit =1) then
        begin
          if (packet FIN, INT or DSN bits =1) then
```

```

comment- should not have these control bits set,
      return unacceptable SYN error.
XMITTERROR (EFP+USYN)

else
  if (packet ACK bit =1) then
    begin
      if ACCEPTABLEACK then
        begin
          SETTCB
          (notify TCP OUTPUT PROCESS to send ACK)
          CONNECTIONSTATE:=ESTABLISHED
          (notify user of connection established)
          HANDLEACK
        end
      else
        XMITTERROR (EFP+USYN)
    end
  else
    comment- simultaneous attempts to open the
      connection.
    begin
      CONNECTIONSTATE:=SIMULINIT
      SETTCB
      (notify TCP OUTPUT PROCESS to send ACK)
    end
  end

-SIMULINIT:
if (packet SYN bit =1) then
  begin
    if (packet seq number equal INITSEQ) then
      comment- duplicate of first SYN, don't send an
        error, but force an ACKnowledgement.
      (notify TCP OUTPUT PROCESS to send ACK)
    else
      begin
        comment- we have received two different SYNs and
          can't tell which to believe, so send error
          message and reinitialize connection and try
          again.
        XMITTERROR (EFP+USYN)
        INITCONNECTION
      end
  end
else
  if (packet ACK bit =1) then
    if ACCEPTABLEACK and INRCVWINDOW then
      begin
        comment- acknowledged our SYN, so connection
          now synchronized.
        CONNECTIONSTATE:=ESTABLISHED
        (notify user of connection established)

```

```

        NORMALCASE
        end

-ESTABLISHED:
if (packet SYN bit =1) then
begin
if (packet seq number equal INITSEQ) then
begin
comment- duplicate of the original SYN that
established connection. force an ACK and
process any data.
(notify TCP OUTPUT PROCESS to send ACK)
if INRCVWINDOW then
NORMALCASE
end
else
comment- unacceptable SYN.
XMITERROR (EFP+USYN)
end
else
begin
if INRCVWINDOW then
NORMALCASE
else
(notify TCP OUTPUT PROCESS to send ACK)
end

INWAIT:
if INRCVWINDOW and (packet FIN bit =1) then
begin
comment- we have sent a FIN and now have received a
FIN. ACKnowledge FIN and see if can delete the
connection.
RCVSEQ:= (packet seq number) + (packet text length)
RCVSEQ:=RCVSEQ + CONTROLLLENGTH (RCVPKTBUFFER)
CONNECTIONSTATE:=FINRECEIVED
(notify TCP OUTPUT PROCESS to send ACK)
if (packet ACK bit = 1) and ACCEPTABLEACK then
HANDLEACK
end

-FINRECEIVED:
if INRCVWINDOW and (packet ACK bit =1) then
if ACCEPTABLEACK then
HANDLEACK

end
else
XMITERROR (EFP+NONX)

return

```

## INRCVWINDOW:

comment- determines if any part of the packet that just came in lies inside the receive window.

## ACCEPTABLEACK:

comment- return TRUE if packet ACKs something we sent that has not yet been ACKed, i.e. LSWEDGE <= ACKfield <= SNDSEQ

## NORMALCASE:

comment- this processes the normal case of putting new data into the right place in the circular reassembly buffer. also processes other possible things in packet.

```
if (packet ACK bit =1) and ACCEPTABLEACK then
    HANDLEACK
if (packet INT bit = 1) then
    HANDLEINT
if (packet text length greater than 0) then
    HANDLEDATA
if (packet DSN bit = 1) then
    HANDLEDSN
if (packet FIN bit = 1) then
    HANDLEFIN
```

```
return
```

## HANDLEACK:

comment- correlates the ACK that came in (and window, etc.) with what we have already put in the control block. it is where confirming ACKs will remove data from the Retransmission ring buffer.

```
if PRECEDE (LASTWSEQ, (packet sequence number) ) then
    begin
        comment- update the send window size if this is the latest
        packet we have seen.

        SNDWS := (packet window size field)
        LASTWSEQ := (packet sequence number)
    end
```

comment- convert next sequence number expected to sequence number of last octet ACKnowledged.

TMPSEQ:=(packet ACK field) - 1

```

LSWEDGE := (packet ACK field)

if RTXCONTROL notequal 0 then
  comment- see if control ACKed.

  if PRECEDE (RTXCNTRLSEQ, TMPSEQ) then
    begin
      comment- if our FIN was ACKed, delete the connection.
      if RTXCONTROL = FIN packet then
        DELETECONNECTION
      RTXCONTROL:=0
    end

  if RTXCOUNT notequal 0 then
    comment- see if any data is ACKed and if so, remove them

    if PRECEDE (RTXDATASEQ, TMPSEQ) then
      begin
        COUNT:=TMPSEQ - RTXDATASEQ + 1
        RTXCOUNT:=RTXCOUNT - COUNT
        RTXPOINTER:=(RTXPOINTER + COUNT) MOD MAXRTXCOUNT
        RTXDATASEQ:=RTXDATASEQ + COUNT
      end

  return

SETTCB:
  comment- fills received information into control block from
  arriving SYN packet
  RCVSEQ is the next sequence number expected,
  SNDWS is the send window size,
  INITSEQ is the initial receive sequence number used,
  LASTWSEQ is the last sequence number used to update send
  window,
  LSWEDGE is the left send window edge.

  SNDWS:= (packet window size)
  INITSEQ:= (packet seq number)
  LASTWSEQ:= (packet seq number)
  RCVSEQ:= (packet seq number) + 1

  return

```

## HANDLEDATA:

comment- this routine moves data from the input packet into the circular reassembly buffer.

INPUTHEAD is a pointer to the head of the reassembly buffer,  
 RCVSEQ is the left receive window edge sequence number,  
 PINDEX is the index into the text field of the input packet  
 REASSMBUFFER is the actual reassembly buffer and  
 REASSMFLAGS is a vector of flags indicating which bytes in  
 the REASSMBUFFER contain valid user data.  
 MAXRCVWS is the length of the reassembly buffer

```

PINDEX:=0
START:= (packet seq number)

if PRECEDE (START, RCVSEQ) then
begin
  PINDEX:=RCVSEQ-START
  START:=RCVSEQ
end

PTR:= [START - RCVSEQ + INPUTHEAD] MOD MAXRCVWS

AMOUNT:= MIN (RCVWS, (packet text length) )

for I:= PINDEX until AMOUNT + PINDEX - 1 do
begin
  REASSMFLAGS (PTR):=TRUE
  REASSMBUFFER (PTR):= (packet text field indexed by I)
  PTR:=(PTR+1) MOD MAXRCVWS
end

if START = RCVSEQ then
  (notify USER of new data received at left window edge)

return
  
```

```

HANDLEINT:
  RCVSEQ:= (packet seq number) + 1
  (notify TCP OUTPUT PROCESS to send ACK)
  (flush receive data)
  (notify USER of INTERRUPT request)

return
  
```

```

HANDLEFIN:
  comment- handle a valid FIN arriving when connection ESTABLISHED

  CONNECTIONSTATE:=FINRECEIVED
  (notify TCP OUTPUT PROCESS to flush send data)
  
```

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```
(notify USER of remote close)
RCVSEQ:= (packet seq number) + (packet text length)
RCYSEQ:=RCYSEQ + CONTROLLLENGTH (RCVPKTBUFFER)
(notify TCP OUTPUT PROCESS to send ACK)
(notify TCP OUTPUT PROCESS to send FIN)

return
```

HANDLEDSN:

```
comment- method for handling DSN is yet unresolved

return
```

ADDRESSCHECK:

```
comment- returns TRUE if the packet is for the one valid
connection. the foreign NET, TCP & PORT address and the
local PORT addresses must agree with those of the open
connection.
```

```
if CONNECTIONSTATE = CLOSED then
    return FALSE

if (packet source NET field) notequal DNET then
    return FALSE

if (packet source TCP field) notequal DTCP then
    return FALSE

if (packet source PORT field) notequal DPORt then
    return FALSE

if (packet destination NET field) notequal SNET then
    return FALSE

if (packet destination TCP field) notequal STCP then
    return FALSE

if (packet destination PORT field) notequal SPORt then
    return FALSE
else
    return TRUE
```

HANDLESPECIALPACKET:

```
comment- handle special functions or error message packets
```

```

case (packet control dispatch field) of
  -SPECIALFUNCTION:
    begin
      case (packet control data octet) of
        -RESETALL:
          if (packet source TCP field) = DTCP then
            RESETCONNECTION

        -RESET:
          if ADDRESSCHECK and ACCEPTABLEACK then
            RESETCONNECTION

        -QUERY:
          if ADDRESSCHECK then
            (send status message)

      end

      -ERROR:
      if ADDRESSCHECK then
        begin
          comment- process error directed at us.

          case (packet control data octet) of
            -USYN:
              if CONNECTIONSTATE = SYNSENT then
                (send a reset)
            else
              if CONNECTIONSTATE = SIMULINIT then
                INITCONNECTION

            -NONX:
            -INACC:
            begin
              case CONNECTIONSTATE of
                -SIMULINIT:
                  INITCONNECTION

                -ESTABLISHED:
                  if INRCVWINDOW then
                    (notify user process of error)

                -FINWAIT:
                  if INRCVWINDOW then
                    DELETECONNECTION

            end
          end
        end
      return
    end
  end

```

## INITCONNECTION:

comment- initialize connection state

## CONNECTIONSTATE:=-SYNSENT

(notify TCP OUTPUT PROCESS to flush send data)

(flush receive data)

comment- pick initial sequence number by adding a constant to  
last sequence number used on previous connection.

SNDSEQ:=-SNDSEQ + 1

(notify TCP OUTPUT PROCESS to send SYN)

return

## CONTROLLLENGTH (packet buffer):

comment- returns the number of octets used in the packet by  
control functions.

## COUNT:=-0

if (packet SYN bit =1) then

COUNT:=-1

if (packet INT bit =1) then

COUNT:=-COUNT +1

if (packet FIN bit =1) then

COUNT:=-COUNT +1

if (packet DSN bit =1) then

COUNT:=-COUNT +1

return COUNT

## PRECED (PARM1, PARM2):

comment- returns true if PARM2 - 2\*\*16 < PARM1. PARM1 and PARM2  
both being 32 bit numbers. this is just a special inwindow  
test that returns true if PARM1 precedes or equals PARM2  
in the circular sequence number space.

## XMITERROR (ERROR CODE):

comment- send an error message to the remote TCP. the error code  
is passed as a parameter. see [3] section 2.4.3 about  
possible error codes.

(swap source & destination socket ids)

(put input packet sequence number in ACK field)

(set Control Dispatch to indicate error present)

(put ERROR CODE in control octet)

(notify TCP OUTPUT PROCESS to send error packet)

(wait for completion of error send)

(set error send complete flag to false)

return

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**DELETECONNECTION:**

comment- set the connection state to CLOSED, notify the user of  
close completion and flush all the queues and stuff.

**CONNECTIONSTATE:-CLOSED**

(notify user process of CLOSE completion)  
(notify TCP OUTPUT PROCESS to flush send data)  
return

## 7 TCP OUTPUT PROCESS LOGIC DOCUMENTATION

## TCP OUTPUT PROCESS:

comment- initialize Net interface.

## INITIALZENETWORK

(notify TCP INPUT PROCESS of initialization complete)

## LOOP: (wait for work to process)

if (need to send error) then

begin

(move packet from RCVPKTBUFFER into SENDPKTBUFFER)

SENDPACKET

(notify TCP INPUT PROCESS that error has been sent)

(set need to send error flag to false)

end

if (need to flush send data) then

begin

comment- flush the send data and retransmission queues.  
first remove any outstanding SENDs.

if (need to send data) then

begin

(set need to send data flag to false)

(notify USER of send completion, ready for new send)

end

BUFBYTECOUNT:=0

comment- then remove any data or control to be retransmitted

RTXCOUNT:=0

RTXCONTROL:=0

RTXWAKEUP:=0

(set need to retransmit data flag to false)

(set need to retransmit control flag to false)

(set need to flush send data flag to false)

end

if (need to send SYN, INT or FIN) then

begin

comment- construct a packet and add the appropriate control  
bits.

## INITIALZEPACKET

if (need to send SYN) then

(set packet SYN bit =1)

if (need to send INT) then

(set packet INT bit =1)

if (need to send FIN) then

(set packet FIN bit =1)

(set need to send SYN, INT and FIN flags to false)

```

SENDPACKET
RTXCNTRLSEQ:=SNDSEQ
RTXCONTROL:= (packet control word field)
SNDSEQ:=SNDSEQ + CONTPOLLENGTH (SENDPKTBUFFER)
end

if (need to send data) then
begin
comment- SPACELEFT is amount of space left in send window
    RTXCOUNT is the number of bytes in the retransmission
    queue,
    MAXRTXCOUNT is the length of the retransmission queue
    buffer,
    RTXSPACE is amount of space left in retransmission queue
    MAXPKTSIZE is maximum number of data bytes in packet
    BUFBYTECOUNT is number of bytes in user send buffer
    BUFFERPOINTER is address of start of user send buffer.

    SPACELEFT:=SNDWS - SNDSEQ + LSWEDGE
    RTXSPACE:=MAXRTXCOUNT - RTXCOUNT
    COUNT:= MIN (SPACELEFT, BUFBYTECOUNT, RTXSPACE, MAXPKTSIZE)
    if COUNT notequal 0 then
        begin
        INITIALIZEPACKET
        if RTXCOUNT = 0 then
            RTXDATASEQ:=SNDSEQ
        PKTPTR:= (index of start of packet text area)
        for I:=1 until COUNT do
            begin
            (copy byte from user buffer into packet)
            (copy byte from buffer into retransmission queue)
            BUFFERPOINTER:=BUFFERPOINTER+1
            RTXPOINTER:=(RTXPOINTER + 1) MOD MAXRTXCOUNT
            PKTPTR:=PKTPTR+1
            BUFBYTECOUNT:=BUFBYTECOUNT-1
            RTXCOUNT:=RTXCOUNT+1
            end
            (set packet text length equal COUNT)
        SENDPACKET
        SNDSEQ:=SNDSEQ + COUNT
    if BUFBYTECOUNT = 0 then
        begin
        (set need to send data flag to false)
        (notify USER of send completion, ready for next send)
        end
    end

    if (need to retransmit data) and CONNECTIONSTATE = ESTABLISHED
        then
    begin
    comment- RTXWAKEUP counts the number of retransmissions
    sent without receiving any ACKs back. it is cleared

```

in HANDLEACK when a valid one comes in and incremented by the clock interrupt routine before notifying the SEND process to retransmit data or control. if the data remains on the retransmission queue too long, the user is notified.

```

if RTXWAKEUP greaterthan maximum allowed then
  comment- the foreign TCP has failed to ACK data that has
  been waiting. it is assumed that the destination
  is not responding

  (notify USER that destination TCP not responding)
else
begin
  comment- now retransmit the data queued up.

  SPACELEFT:=SNOWS - RTXDATASEQ + LSWEDGE
  COUNT:= MIN (SPACELEFT, RTXCOUNT, MAXPKTSIZE)
  if COUNT notequal 0 then
    begin
      INITIALIZEPACKET
      RTXPTR:=RTXPOINTER
      PKTPTR:=(index of start of packet text area)
      for I:=1 until COUNT do
        begin
          SENDPKTBUFFER(PKTPTR):=RTXBUFFER(RTXPTR)
          PKTPTR:=PKTPTR+1
          RTXPTR:=(RTXPTR+1) MOD MAXRTXCOUNT
        end
        (packet sequence number):= RTXDATASEQ
        (packet text length):= COUNT
        SENDPACKET
      end
    end
  (set need to retransmit data flag to false)
end

if (need to retransmit control) then
begin
  if RTXCONTROL notequal 0 then
    begin
      if RTXWAKEUP greaterthan maximum allowed then
        begin
          (notify USER that destination TCP not responding)
          if RTXCONTROL equals FIN packet then
            comment- a FIN packet has timed-out. so close
            the connection anyway.
            DELETECONNECTION
        end
    end
  else
    begin
      SPACELEFT:=SNOWS - RTXCNTRLSEQ + LSWEDGE
    end
end

```

```

        if SPACELEFT greaterthan 0  then
            begin
                INITIALIZEPACKET
                (packet sequence number):= RTXCNTRLSEQ
                (packet control word):= RTXCONTROL
                SENDPACKET
            end
        end
    end
    (set need to retransmit control flag to false)
end

if (need to send ACK)  then
begin
    INITIALIZEPACKET
    SENDPACKET
end

goto LOOP

```

## INITIALIZEPACKET:

comment- initialize the internet header

```

    (move SNOSEQ into packet seq field)
    (move foreign socket id into packet)
    (move local socket id into packet)
    (move RCVWS into packet)
    (zero out rest of packet header)
    if (need to send ACK)  then
        begin
            comment- piggyback ACK onto data or control packet
            (set packet ACK bit =1)
            (put receive left window edge in ACK field)
            (set need to send ACK flag to false)
        end
    return

```

## SENDPACKET:

comment- calculate a checksum and put it in the header and then sent it.

```

    (put zero in packet checksum field)
    (packet checksum field):=CHECKSUM (SENDPKTBUFFER)
    NETOUTPUT (SENDPKTBUFFER)
    return

```

## 8 ARPANET INTERFACE LOGIC DOCUMENTATION

INITIALZENETWORK:

comment- initialize the device drivers and send NOPs to IMP

(reset network device driver)

(construct IMP NOP message)

for I:=1 until 4 do

begin

comment- send four NOPs to the IMP

(give NOP message to network driver to send)

(wait until message sent)

end

return

NETINPUT (PACKETBUFFER):

comment- start input from IMP

LOOP: (start message input from IMP)

(wait until finished)

if (message not on experimental links, 155-158) then  
goto LOOPif (message type notequal regular or minimum effort) then  
goto LOOP

comment- return message to TCP

return

NETOUTPUT (PACKETBUFFER):

(initialize IMP-HOST header)

(give to network device driver to send)

(wait until message sent)

return

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January 25, 1976

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